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CATARACT

Propensity-matched comparison of postoperative stability and visual outcomes of toric intraocular lens with or without a capsular tension ring and updated meta-analysis

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Abstract

Purpose To assess the contribution of capsular tension ring (CTR) to postoperative stability and visual outcomes of a plate-haptic toric intraocular lens (IOL).

Methods This prospective cohort study was performed among patients underwent toric IOL (AT TORBI 709 M) implantation with or without CTR at the Eye and ENT hospital between April 2020 and November 2021. Propensity score matching (PSM) was performed to balance baseline factors. Postoperatively, uncorrected distance visual acuity (UCVA) and residual astigmatism, as well as IOLs' rotation, tilt, and decentration, were analyzed. Grouped multiple linear regression analysis was used to model predictive factors of rotation in each group. Additionally, a meta-analysis of data from 4 publications (284 eyes) and current study was performed to evaluate the effect of CTR co-implantation on toric IOL rotation.

Results After PSM, 126 eyes from each group were included for further analysis. Postoperatively, UDVA was 0.31 ± 0.38 logMAR and 0.27 ± 0.36 logMAR in the CTR and NCTR groups, respectively ($P = 0.441$), and residual astigmatism was 0.75 ± 0.52 D and 0.86 ± 0.65 D, respectively ($P = 0.139$). The rotation of toric IOL was significantly smaller in the CTR group than in the NCTR group (4.63 ± 6.27 vs. 10.93 ± 16.05 degrees, $P < 0.001$). The regression models of the two groups and the coefficients of LT were significantly different ($P < 0.001$ and $P = 0.001$, respectively). Furthermore, the meta-analysis confirmed that CTR co-implantation reduced toric IOL rotation (MD, − 1.59; 95% CI, − 3.10 to − 0.09; $P = 0.038$).

Conclusion CTR enhances rotational stability of toric IOL by reducing the impact of LT, and CTR co-implantation is recommended in patients with lens thickness (LT) ≥ 4.5 mm, white-to-white (WTW) ≥ 11.6 mm, or high preexisting astigmatism.

Keywords Propensity-matched analysis · Toric intraocular lens · Capsular tension ring · Postoperative stability · Meta-analysis

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Key messages

- Rotational stability of toric intraocular lens is crucial to good visual outcome.
- This study indicates CTR co-implantation decreases toric IOL rotation by reducing the impact of LT.
- CTR co-implantation is highly recommended in patients with LT ≥ 4.5 mm, WTW ≥ 11.6 mm, or high preexisting astigmatism.

Introduction

Reportedly, 29–47.3% of patients undergoing cataract surgery have preexisting astigmatism > 1 diopter (D), and toric intraocular lens (IOL) implantation has been an effective method to achieve good visual outcomes and spectacle independence in these patients [1–5]. However, deviation from the intended position decreases the astigmatism correction, and even visual function might deteriorate when the deviation exceeds 30° [6]. Consequently, reduction in postoperative toric IOL rotation has been a significant concern.

Numerous studies have focused on exploring effective methods to enhance the rotational stability of toric IOLs by analyzing the factors influencing rotation (ocular biometric parameters, properties of toric IOLs, and surgical factors) [7–9]. Recently, methods such as capsular tension ring (CTR) co-implantation have been reported to stabilize toric IOL in cataract patients with long axial length or zonular instability in some studies [10, 11]. What's more, a prospective randomized clinical trial included 50 eyes found that CTR significantly decreased toric IOL rotation in cataract patients at 3 months postoperatively [12]. Nevertheless, no significant differences were found in toric IOL rotation with or without CTR in other two clinical studies [13, 14]. Thus, whether the use of CTR is beneficial for the rotational stability of toric IOL remains unclear.

This study aimed to evaluate the contribution of the use of CTR in clinical visual outcomes and rotational stability of toric IOL after cataract surgery and provide scientific recommendations for CTR co-implantation. In addition, a meta-analysis of published and current data was conducted to further assess rotational stability of toric IOL with or without CTR.

Method

Study subjects

This non-randomized, prospective observational, cohort study recruited patients who underwent uneventful lens phacoemulsification and toric IOL AT TORBI 709 M (Carl Zeiss Meditec, Jena, Germany) implantation between April 2020 and November 2021 at the Eye and ENT hospital of the Fudan University, Shanghai. Cataract patients with corneal astigmatism ≥ 0.75 D were enrolled in the study. The exclusion criteria were as follows: irregular astigmatism, preexisting corneal pathology, small pupil, glaucoma, zonular dehiscence, a history of ocular trauma or surgery, uveitis, and intraoperative complications such as posterior capsule rupture.

The cohort study was performed in accordance with the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board of the Eye and ENT hospital. Written informed consent was obtained from all patients.

Preoperative assessment

Preoperatively, the patients underwent complete ophthalmic examinations including subjective refraction, slit-lamp microscopy, intraocular pressure measurement, fundus examination, B-scan ultrasonography, corneal tomography (Pentacam HR, OCULUS Optikgerate, Wetzlar, Germany), and ocular biometry (IOLMaster 700, Carl Zeiss Meditec, Jena, Germany). The IOL spherical power, cylinder power, and the alignment axis were calculated using the manufacturer's online calculator (https://zcalc.meditec.zeiss.com/). CTR was used regardless of AL and LT, and the size of CTR was determined by the measurement data of white-to-white (WTW).

Surgery

Preoperatively, all patients were seated in upright sitting positions and their heads were aligned carefully. Limbal reference marks at 0° and 180° positions were marked using a slit-lamp microscope. All surgeries were performed with a 2.3-mm clear corneal incision under general anesthesia by an experienced surgeon (J.Y.) using a standard procedure. The clear corneal incision is made at 90° when the preoperative steep axis of corneal astigmatism is between 1 and 89°; otherwise, the incision is located on the preoperative steep axis of corneal astigmatism. Afterwards, a continuous curvilinear capsulorhexis (CCC) measuring approximately 5.4 mm, hydrodissection, and phacoemulsification were performed, followed by capsular polishing. Subsequently, the IOL was implanted in the capsular bag and adjusted to the desired position. After completely removing the viscoelastic material, the IOL axis was verified, and the incisions were hydrated. The Callisto Eye System (Carl Zeiss Meditec, Jena, Germany) was used to guide the entire operation. CTR (Eyebright Meditec, Being, China) was implanted in eyes through the same corneal incision before toric IOL implantation. Postoperatively, all eyes were treated with prednisolone acetate 1%, levofloxacin 0.5%, and pranoprofen eye drops 0.1%.

Postoperative examination

All patients underwent complete ophthalmic examinations at the outpatient clinic, including uncorrected distance visual acuity (UDVA), refraction, silt-lamp microscopy, and OPD-Scan III (Nidek, Gamagori, Japan) 1 day, 3 days, 1 week, 2 weeks, 1 month, and 3 months postoperatively. Repositioning surgery was performed two weeks after cataract surgery, if patients' visual outcomes were affected by toric IOL rotation; and patients were followed at 1 day, 3 days, 1 week, 2 weeks, and 1 month after repositioning surgery. UDVA, refraction, and slit-lamp microscopy data were recorded, and OPD-Scan III data were recorded 2 weeks postoperatively. After the pupil was dilated, the IOL axis was recorded by a senior surgeon (C. L.) using the same slit-lamp microscope. Toric IOL rotation was defined as the difference between the target and final axis. The tilt data were directly obtained from the wavefront mode of the OPD-Scan III aberrometer. Decentration was defined as the distance between the center of the toric IOL and the visual axis and was calculated using Adobe Photoshop software (Adobe, San Jose, USA) on the retro image exported from the OPD-scan aberrometer.

Propensity score matching

Propensity score matching was performed to balance significant baseline characteristics that might interfere with the rotation of toric IOLs. Through logistic regression analysis, propensity scores were estimated with covariates such as age, AL, anterior chamber depth (ACD), LT, WTW, and preexisting corneal astigmatism (ΔK) to represent the probability of assignment. The subjects in the CTR group were matched 1:1 with those in the NCTR group based on the propensity score. The matching algorithm was radius matching without replacement with a caliper value of 0.02. To determine the balance between the matched subjects, the standardized mean difference for each included covariate was calculated before and after matching. Subjects with an eligible match were included for further analysis.

Data analysis

Postoperative data from the second week were used to analyze toric IOL rotational stability. All statistical analyses were performed using SPSS22.0 (IBM, Armonk, NY, USA) and STATA 16.0 (Stata Corp LP, College Station, TX, USA). Continuous data are presented as the mean ± standard deviation. After propensity matching, grouped multiple linear regression analysis with absolute toric IOL rotation as the dependent variable, and age, AL, ACD, LT, WTW, and ΔK work as independent variables was performed to model the predictive factors in different groups. The F-test was utilized to evaluate each regression model, and R-squared was utilized to determine the proportion of variance in the dependent variable explained by the independent variables. The Chow test was utilized to compare the differences between the CTR and NCTR equation models [15]. If significant, structural changes in the two models exist. Subsequently, the coefficient differences between the two equations were compared (Cohen & Cohen), evaluating the moderating effect of CTR on the association between each independent variable and toric IOL rotation [16]. In addition, subgroup analysis was carried out to assess the IOL rotation in the CTR and NCTR groups based on AL, ACD, LT, WTW, and ΔK subgroups. When the interaction was significant, the differences in IOL rotation and residual astigmatism between the CTR and NCTR groups of each subgroup were evaluated using *t*-test. P-value < 0.05 indicated statistical significance (two-sided p-value).

Meta-analysis

In February 2022, we systematically searched the databases of PubMed, Embase, and Cochrane Central Library to identify all relevant articles that assessed the stability of toric IOLs with or without CTR. The search terms included: ("cataract" and "surgery") and ("toric intraocular lens" or "toric IOL") and ("capsular tension ring" or "CTR"). The studies were restricted to those published in English. Two reviewers (Ma and Han) completed the identification of the relevant studies, study selection, quality assessment, and data extraction. Meta-analyses of these studies and the current study were performed using STATA 16.0. A combined MD with its 95% CI was used to express the postoperative rotation of toric IOL. When the results were expressed in medians and quartiles, the data were converted using "Eq. 3" summarized by Wan et al. to standardize the data [17].

Results

Among 374 eligible patients, 437 eyes of 319 patients who provided written informed consent were recruited for inclusion in this study; 362 eyes (82.8%) of 280 patients completed at least the 1-month follow-up (185 eyes in the

Table 1 Patient characteristics

Parameters	Entire cohort (n = 362)					Propensity score-matched cohort (n = 252)				
	NCTR (n = 185)		CTR (n = 177)			NCTR (n = 126)		CTR (n = 126)		
	Mean	SD	Mean	SD	P	Mean	SD	Mean	SD	P
AGE (year)	68.67	10.65	64.71	10.72	0.000*	65.92	10.51	65.11	10.77	0.546
AL (mm)	24.86	2.29	26.36	2.66	0.000*	25.47	2.36	25.28	2.14	0.519
ACD (mm)	3.10	0.48	3.26	0.41	0.000*	3.19	0.49	3.19	0.41	0.979
LT (mm)	4.51	0.44	4.44	0.45	0.125	4.45	0.45	4.45	0.44	0.929
WTW (mm)	11.62	0.50	11.68	0.42	0.193	11.65	0.49	11.67	0.42	0.837
ΔK (D)	2.05	0.88	1.78	0.70	0.001*	1.88	0.74	1.83	0.75	0.631

AL axial length; *ACD* anterior chamber depth; *LT* lens thickness; *WTW* white-to-white diameter; Δ*K* preexisting corneal astigmatism; *D* diopter

*Statistically significant ($P < 0.05$)

CTR group and 177 eyes in the NCTR group). Among these patients, the baseline characteristics, except WTW and LT, were significantly different between the two groups. After developing the propensity score, 126 eyes in the CTR group were matched with 126 eyes in the NCTR group, and the matched eyes were similar in all baseline characteristics ($P > 0.05$) (Table 1). Postoperative UDVA was 0.31 ± 0.38 logMAR and 0.27 ± 0.36 logMAR in the CTR and NCTR groups, respectively ($P = 0.441$). The distribution of preoperative and residual astigmatism in the two groups is shown in double-angle plots (Fig. 1).

Postoperative stability of toric IOL

In our matched dataset, the overall decentration in the CTR and NCTR groups was 0.33 ± 0.26 mm and 0.32 ± 0.25 mm, respectively ($P = 0.872$), and the tilt was 0.22 ± 0.22 µm and 0.33 ± 0.50 µm, respectively ($P = 0.104$) (shown in Fig. 2). The degree of rotation differed significantly between the groups with and without CTR (4.63 ± 6.27, 10.93 ± 16.05, $P = 0.000$). In addition, 21 eyes required repositioning surgeries because of undesired visual outcomes caused by toric IOL rotation (Table 2, 15 eyes in the NCTR group, and 6 in the CTR group).

Subgroup analysis of toric IOL rotation and residual astigmatism

We further analyzed the toric IOL rotation in the CTR and NCTR groups of different subgroups. Patients are categorized based on AL ≥ 26 mm, LT ≥ 4.5 mm, and the median value of age (66 y), ACD (3.2 mm), WTW (11.6 mm), and ΔK (1.715 D), respectively. The interaction between CTR use and WTW or LT was significant ($P = 0.049$ and $P = 0.002$, respectively), but no significant interaction between CTR use and age, AL, ACD, or ΔK was found ($P = 0.061$, $P = 0.478$, $P = 0.273$, and $P = 0.379$, respectively). Therefore, the comparison of toric IOL rotation with or without CTR was performed in the LT and WTW subgroups (Fig. 3). The results showed that the degree of rotation was significantly greater in the NCTR group than in the CTR group when LT ≥ 4.5 mm and WTW ≥ 11.6 mm (all $P < 0.05$).

The absolute residual astigmatism was not significantly different between the CTR and NCTR groups (0.75 ± 0.52 D and 0.86 ± 0.65 D, respectively; $P = 0.139$). Because residual astigmatism was associated with toric IOL rotation and preoperative corneal astigmatism, we further compared residual astigmatism with or without CTR in the ΔK, LT, and WTW subgroups (Fig. 3). The results showed that statistical significance was found only in the LT ≥ 4.5 mm subgroup (0.70 ± 0.49 D and 1.07 ± 0.78 D, respectively; $P = 0.003$).

Analysis of rotational changes with CTR use

To further investigate how CTR enhances the rotational stability of the toric IOL, we performed multiple linear regression analyses with absolute toric IOL rotation as the dependent variable, and age, AL, ACD, LT, WTW, and ΔK work as independent variables by grouping (Table 3). Compared with the Chow test, the regression models of the two groups differed significantly ($P < 0.001$), indicating that CTR contributes to structural changes in the two models. Furthermore, of the 6 variables in the model, only the coefficients of LT differed significantly across the two models ($P = 0.001$), suggesting that the influence of LT on toric IOL rotation differed significantly in the CTR and NCTR groups.

Meta-analysis

Forty-nine clinical research articles were initially retrieved through an electronic search. Reviewing the abstract and full

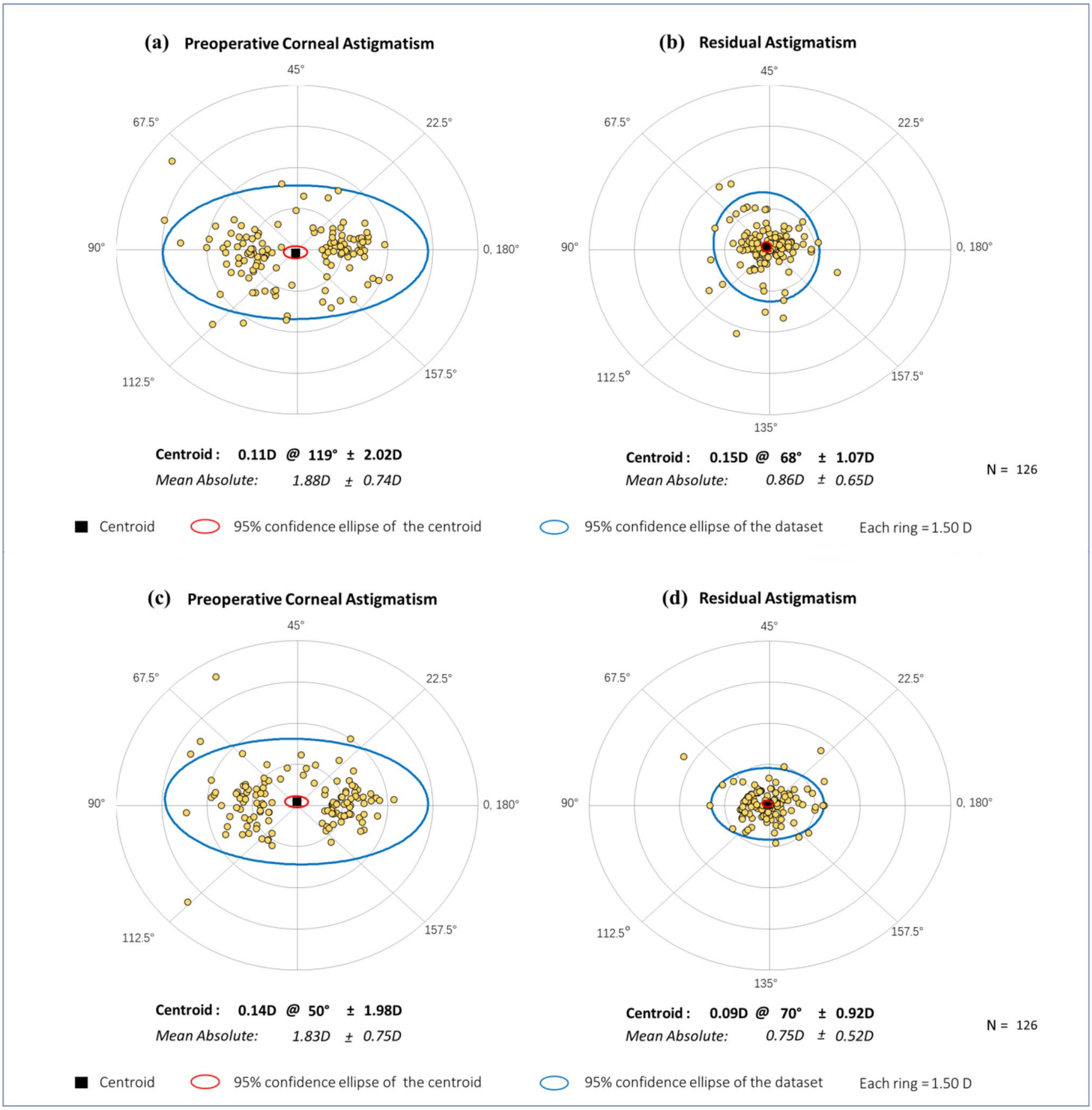

Fig. 1 Double-angle plots of corneal astigmatism and residual astigmatism. **a**. Preoperative corneal astigmatism in NCTR group. **b** Residual astigmatism in NCTR group. **c** Preoperative corneal astigmatism in CTR group. **d** Residual astigmatism in CTR group

text showed that only two random control studies and two observational studies fulfilled the inclusion criteria. Meta-analysis of the data from the four studies and the current study showed a significant decrease in toric IOL rotation with CTR co-implantation compared with toric IOL implantation without CTR in the random effects model (MD, −1.59; 95% CI, −3.10 to −0.09; $P=0.038$), with significantly high heterogeneity ($P<0.001$, $I^2=85.5\%$) (Fig. 4).

Discussion

In our former study, we observed that toric IOL rotation mainly occurred within 2 weeks postoperatively. Hence, data from the 2-week follow-up were used for the analysis in our study. After propensity score matching, 252 eyes of 210 patients who underwent toric IOL implantation were enrolled in this study (126 eyes in each group). Postoperatively, the degree of rotation was significantly smaller in the CTR group than that in the NCTR

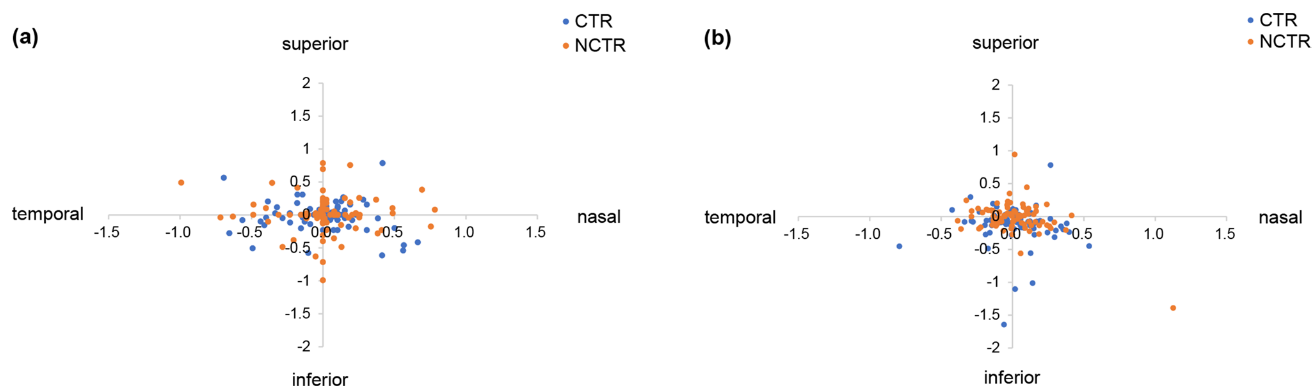

Fig. 2 The distribution of decentration and tilt. **a**. The decentration of toric IOL in CTR and NCTR groups. **b** The tilt of toric IOL in CTR and NCTR groups

group. Similar promising results were obtained from three previous comparative studies [12, 18, 19]. The results of our meta-analysis are in accordance with those of our cohort study; considerable heterogeneity was demonstrated by the included studies, which may be attributed to the differences in study design, sample size, geographical region, race, and properties of toric IOLs. Notably, given the size (nearly twice as large as the former largest study) and real-world setting (PSM) of our study, our results would prove that CTR use enhances the rotational stability of toric IOL with more credibility and reliability.

To further assess how CTR co-implantation reduces toric IOL rotation, this study assessed the potential risk factors (age, LT, AL, WTW, and ACD) for toric IOL rotation in the CTR and NCTR groups using multiple linear regression analysis. The results showed that only LT positively correlated with toric IOL rotation in the NCTR group. Notably, comparing the regression models and coefficients, the influence of LT on toric IOL rotation differed significantly in the CTR and NCTR groups, resulting in significant structural changes in the models. Therefore, to the best of our knowledge, this study is the first to reveal that CTR co-implantation reduces, but does not eliminate, plate-haptic toric IOL rotation by alleviating the influence of LT. A reasonable explanation is that thicker lenses may be associated with larger capsular bags, and CTR might increase the rotational stability of the toric IOL by taking up of the slack in a big lens, decreasing the space between the IOL and posterior capsule and increasing the friction between the capsular bag and toric IOL haptics [20, 21]. In addition, based on data from 351 eyes, we previously established and evaluated a risk prediction model for plate-haptic toric IOL rotation using binary logistic regression analysis and receiver operator characteristic curves, revealing that LT is an independent influencing factor with a cut-off value

Table 2 Characteristics of patients requiring reposition surgery

Parameters	NCTR (n = 15)		CTR (n = 6)	
	Value	Range	Value	Range
Age (year)	72.93 ± 6.58	61–82	73.83 ± 6.85	64–83
Gender (male/female)	5 / 9	/	2 / 4	/
Eye(right/left)	8 / 7	/	4 / 2	/
AL (mm)	26.17 ± 2.23	23.61–31.16	25.54 ± 1.56	23.47–28.27
ACD (mm)	3.32 ± 0.49	2.4–4.23	3.2 ± 0.3	2.75–3.99
LT (mm)	4.81 ± 0.52	3.87–5.68	4.48 ± 0.32	4.01–4.82
WTW (mm)	11.93 ± 0.47	11–12.5	11.33 ± 0.42	11–12.1
ΔK (D)	1.77 ± 0.65	0.95–3.21	1.64 ± 0.46	1.15–2.45
Two-week rotation after cataract surgery (°)	44.53 ± 24.48	8–76	19.17 ± 15.94	8–47
Two-week rotation after repositing surgery (°)	4.40 ± 4.15	0–13	2.5 ± 2.07	0–5

AL axial length; *LT* ens thickness; *ACD* anterior chamber depth; *WTW* white-to-white diameter; *D* diopters; Δ*K* preexisting corneal astigmatism; *RAS* residual astigmatism

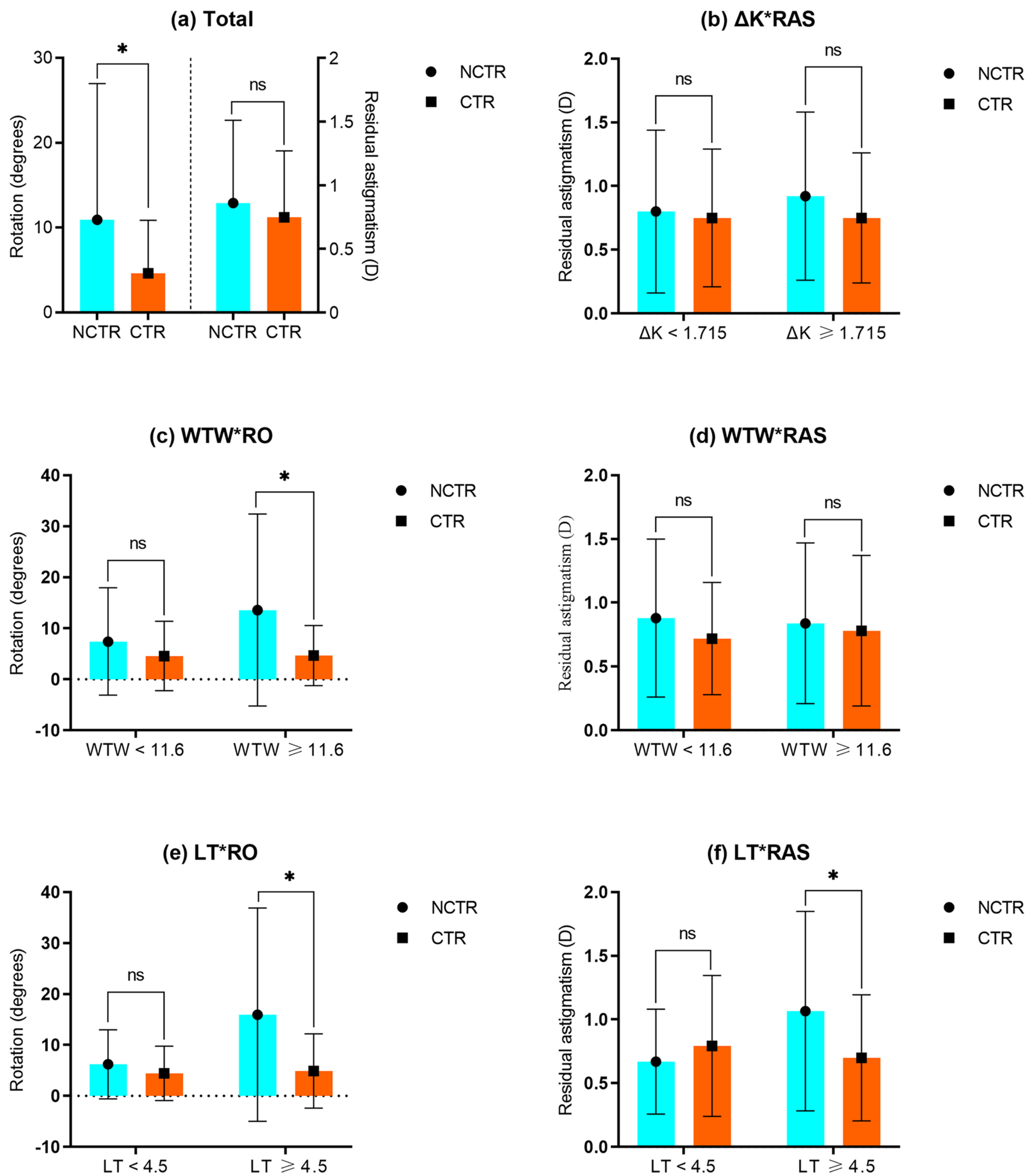

Fig. 3 Subgroup analysis. **a** Toric IOL rotation and residual astigmatism in NCTR and CTR group. **b** Residual astigmatism in different preexisting corneal astigmatism subgroups of the NCTR and CTR groups ($P=0.641$, $P=0.108$, respectively). **c** Toric IOL rotation in different WTW subgroups of the NCTR and CTR groups ($P=0.103$, $P<0.001$, respectively). **d** Residual astigmatism in different WTW subgroups of the NCTR and CTR groups ($P=0.132$, $P=0.496$, respectively). **e** Toric IOL rotation in different LT subgroups of the NCTR and CTR groups ($P=0.089$, $P<0.001$, respectively). **f** Residual astigmatism in different LT subgroups of the NCTR and CTR groups ($P=0.146$, $P=0.003$, respectively). RO = rotation, RAS = residual astigmatism, ΔK = preexisting corneal astigmatism, WTW = white-to-white, LT = lens thickness,* Statistically significant ($P<0.05$)

Table 3 Results from multiple regression model

Variables/constant	NCTR B	SE	t	P	β	CTR B	SE	t	P	β	Coefficient difference
Constant	−126.165*	35.47	−3.557	0.001	-	−23.92	18.004	−1.329	0.187	-	-
AGE	0.26	0.137	1.893	0.061	0.17	0.141	0.062	2.275	0.025*	0.242	0.36
AL	0.206	0.676	0.305	0.761	0.03	0.447	0.316	1.413	0.16	0.153	0.696
ACD	4.667	3.993	1.169	0.245	0.142	2.479	1.977	1.254	0.212	0.161	0.484
LT	10.555	3.815	2.767	0.007*	0.293	0.548	1.71	0.32	0.749	0.039	0.001*
WTW	5.084	3.044	1.67	0.098	0.156	−0.204	1.504	−0.136	0.892	−0.014	0.084
K	−3.427	1.786	−1.918	0.057	−0.158	0.067	0.751	0.09	0.929	0.008	0.061
N	126					126					-
R^2	0.224					0.065					-
Adjusted R^2	0.185					0.018					-
F	F (6, 119) = 5.726, P = 0.000					F (6, 119) = 1.386, P = 0.226					-

AL axial length; *ACD* anterior chamber depth; *LT* lens thickness; *WTW* white-to-white diameter; *ΔK* preexisting corneal astigmatism; *D* diopter

*Statistically significant ($P < 0.05$)

of 4.47 mm. Therefore, 4.5 mm of LT was used to group patients for further subgroup analysis of the CTR and NCTR groups. The results of the LT subgroup analysis showed that the rotation and residual astigmatism in the CTR group were significantly smaller than those in the NCTR group when LT was ≥ 4.5 mm, supporting the use of CTR in toric IOL implantation for eyes with thick lenses.

The capsular bag diameter is another significant element for predicting the size of the capsular bag, and the horizontal corneal WTW diameter has been used to estimate the capsular bag diameter in some previous studies [22]. Moreover, our group's previous study found that WTW positively correlated with toric IOL rotation [23]. In our study, with the significant interaction between CTR use and WTW, CTR use significantly reduced toric IOL rotation when WTW ≥ 11.6 mm, implying that WTW ≥ 11.6 mm was also a critical parameter for determining CTR implantation. Reportedly, toric IOL rotation was correlated with AL [24], and CTR increased toric IOL stability in highly myopic eyes (AL ≥ 26 mm) [10]. However, our results found no significant interaction between AL and CTR use, suggesting that the effect of CTR on reducing IOL rotation was the same whether AL ≥ 26 mm or AL < 26 mm. It is possible that the result is owing to the non-linear association between AL and LT or WTW [23, 25]. Therefore, it would be more appropriate to consider LT and WTW when deciding on the use of CTR in toric IOL implantation.

The contribution of CTR use to residual astigmatism was uncertain in previous studies [13, 15, 18, 19]. In the current study, residual astigmatism was not significantly different between the groups with or without CTR in the overall analysis. According to previous studies, every degree of rotation results in nearly 3.3% loss of cylindrical power correction [6]. Hence, except for other factors, such as incorrect cylindrical power calculation or surgery impact, the degree of residual astigmatism is associated with preexisting corneal astigmatism and postoperative toric IOL rotation [26]. However, the CTR and NCTR subgroup analyses showed that the changes in residual astigmatism were not wholly consistent with those of toric IOL rotation, possibly owing to the non-linear association between residual astigmatism and toric IOL rotation. Although there was no significant interaction between preexisting astigmatism and CTR use, we still believe that more attention should be paid to the rotational stability of the toric IOL in patients with high preexisting astigmatism because 1 degree of rotation in these patients results in greater residual astigmatism.

However, the importance of CTR secure implantation should be noted. According to our clinical observation, post capsule rupture occurred in two high myopia cases due to the CTR implantation. Because high myopia patients usually had deeper anterior chamber depths and larger anterior segment space. The regular usage of OVD is insufficient to support the capsular bag; thus, the head of CTR may easily poke the posterior capsule when implanting CTR. Except for adequate use of the OVD,

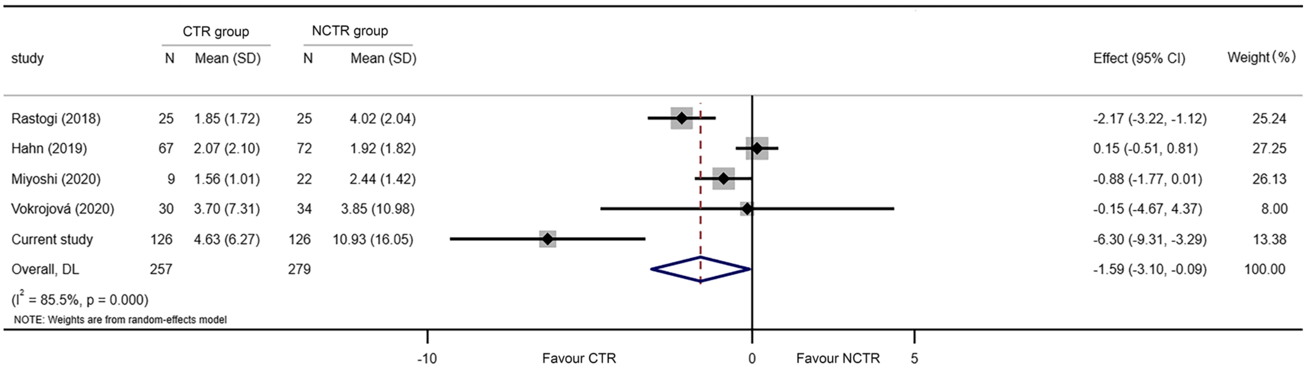

Fig. 4 Meta-analysis of published data and the current study on the contribution of CTR use to toric IOL rotation

the size of CTR should be selected based on the preoperative horizontal corneal diameter (WTW). Moreover, the CTR should be implanted parallel to the capsular bag to avoid poking the posterior capsule. If the resistance exits while implanting CTR, further OVD injection is required. If this attempt fails to eliminate the resistance, the implantation direction can be changed (i.e., from anti-clockwise to clockwise).

Limitation

First, insufficient pupil dilation of some eyes and incorrect head positions, as well as some slight differences in the width of the slit-lamp light, axis reading, and manual calculation of decentration, could have resulted in errors in evaluating toric IOL stability. Second, the failure to examine preoperative decentration of the capsular bag restricted exploring CTR's contribution to the toric IOL decentration. Third, the ideal study would have been a randomized control trial or a study where CTR is randomly inserted in one eye of a patient undergoing bilateral toric IOL implantation. Thus, we conducted the propensity score matching analysis to compensate for not randomly assigning participants and eliminate the potential bias. Fourth, we did not further analyze the considerable heterogeneity, as only five studies were included in the meta-analysis. Therefore, large-scale studies with high-quality data are further required to fully assess the contribution of CTR use to toric IOL stability, visual outcomes, and residual astigmatism.

Conclusion

The current study showed that CTR use enhances the rotational stability of toric IOL by reducing the impact of LT. Thus, CTR co-implantation is strongly recommended in patients with LT ≥ 4.5 mm, WTW ≥ 11.6 mm, or high preexisting astigmatism.

Author contribution All authors contributed to the study design and data collection; Jianfeng Luo, Dongmei Ma, and Zhixiang Hua analyzed the data and created the figures and tables; Xiaoyan Han and Dongmei Ma drafted the manuscript; Jin Yang modified the manuscript.

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Data availability Data are available on reasonable request from the corresponding author.

Declarations

Ethics approval and consent to participate The study was performed in accordance with the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board of the Eye and ENT hospital. Written informed consent was obtained from all patients.

Consent to publication Not applicable.

Competing interests The authors declare no competing interests.

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